UNDERGROUND WORKINGS DETECTION AT THE FIMISTON OPEN PIT KCGM

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Abstract

The Kalgoorlie Consolidated Gold Mines (KCGM) Fimiston Open Pit is located on the eastern boundary of the Kalgoorlie-Boulder City and is mining an area traditionally known as the Golden Mile. The pit area has been continuously worked since 1893, predominantly by underground mining methods and more recently through open cut mining.

There are over 2000 km of old mine headings and numerous stopes under the open pit area. KCGM has interpreted and digitized the underground mine plans and stope sections into a common database. However, discrepancies exist between the existing plans that form the database and the reality in the pit in terms of the location and shape of stopes and drives. At times this discrepancy is quite significant. The most serious case is when an old working is not shown on the plans and opens to the surface in an unplanned manner, which is called a “surprise’.

Special criteria and procedures have been developed and implemented to keep personnel and machinery from being exposed to unsafe ground. It is of primary importance to accurately define the location and outline of underground workings in advance. Probe drilling has been used as the key tool for that purpose. Laser scanning has been utilized to map open voids successfully. The mapping results can be displayed with 3D modeling software.

Various geophysical methods have also been trialed on site to detect underground workings. These include the ground probe radar (GPR), micro-gravity, the multi-electrode resistivity method, the cross-hole radio wave tomography, the transient electromagnetic method (TEM) and the micro-seismic tomography. The ability to detect voids varies from method to method. The GPR has achieved the best results among the methods mentioned above. However, to date the application of geophysical tools have not proven to be a practical alternative that can be adapted to fit in with the production cycle.

INTRODUCTION

The Fimiston Open Pit (commonly referred to as the “Super Pit”) is part of the Kalgoorlie Consolidated Gold Mines (KCGM) operations in Kalgoorlie-Boulder. The open pit is located on the eastern boundary of the Kalgoorlie-Boulder City and is mining an area traditionally known as the Golden Mile. The mine area has been continuously worked since 1893, predominantly by underground mining methods and more recently through open cut mining. Consequently, the

Fimiston Open Pit is now mining through a dense network of underground development workings with open and filled stopes of varying sizes. Figure 1 is a photo taken from the pit showing some open and filled stopes intersecting with pit slope.

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Figure 1. Open and filled stopes intersecting with pit slope (the batter is 20 m high).

There are over 2000 km of old mine headings and numerous stopes under the open pit area. KCGM has interpreted and digitized the underground mine plans and stope sections into a common database. However, discrepancies exist between the existing plans that form the database and the reality in the pit in terms of the location and shape of stopes and drives. At times this discrepancy is quite significant. The most serious case is when an old working is not shown on the plans and opens to the surface in an unplanned manner, which is called a “surprise’.

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FLAGGING

On the pit floor, areas with subsidence risk are flagged with black/white (B/W) or red/white (R/W) tape depending on the risk level. Black/white flagging indicates a known area of underground workings that has low probability of developing a void to surface and is deemed safe for heavy vehicle access if equipped with a roll-over-protection system. Red/white tape indicates a known or suspected void area with insufficient cover. In other words, the area has a high probability of developing a void to surface.

Flagging is designed and placed based on the knowledge and understanding of underground workings including their size, shape, type of fills and filling condition. No access is allowed to black/white and red/white taped areas. Any personnel on foot entering the B/W or R/W area must have prior approval and wear a personal fall arrest device attached to a secure anchor point.

UNDERGROUND WORKINGS DETECTION AND DELINEATION

Underground working detection consists of detection and delineation. Detection is about finding unmapped workings partially or fully. Delineation is to define the shape and spatial location of those underground workings. Both activities are equally important. KCGM has carried out substantial research and production trials to improve voids detection and delineation techniques. These include probe drilling, cavity mapping using laser scanners and geophysical methods.

Probe drilling continues to be used as the key tool to delineate underground workings and has been proven to be the most reliable and practical method. Down hole laser scanners have been found to be very effective for mapping the geometry of open voids. The scanner is deployed into a stope through a bore hole from surface.

Theoretically, geophysical methods can detect underground workings. But from the trials conducted so far in the pit, none of the geophysical methods can delineate workings to a satisfactory degree due, mainly, to complex geological structures and the time window allowed.

Probe drilling

KCGM has developed comprehensive probing procedures. The majority of probe holes are drilled using Tamrock type drill rigs with 89mm diameter as shown in Figure 2. Probe holes along the hanging wall of a stope are planned at 10 metres intervals and planned at 15 metres along the footwall. Most probes are 16 metres deep and inclined at 80 degrees towards a stope. Generally two or more probes are drilled on one section depending on the ground condition encountered, for example:

If the first hole encounters *more* than “safety cover”,
Then step forward 2 metres to drill another hole.
If the first hole encounters *less* than “safety cover”’,
Then step back 2 meters to drill another hole.

Figure 2. A Tamrock type probe rig with long reach arm.

The “safety cover” is decided based on geotechnical analysis and experience. Figure 3 shows 5 probe holes drilled on a section from both hanging wall and footwall side. Points A and B will help to identify the hanging wall of a stope for the next bench. If probes can penetrate a stope, point C and D will define the footwall of the stope. Points on the surface will help to fine-tune the tape position on the current bench. A 4.5m solid vertical cover is deemed safe. An area with less than 4.5m solid vertical cover generally requires flagging. Type of fill and filling condition will also be recorded.

Probe drilling defines the spatial location of a stope and the filling condition inside a stope. However, probe drilling is relatively expensive. The density of probe holes is limited by cost with the ground condition between two probe sections generally based on interpolation.

The 80 degree probe angle is chosen with consideration to the safety of the probe rig, drilling efficiency and the average dip angle of the stopes. Obviously, a flat probe angle will cover a larger horizontal distance and subsequently increase the forward distance. However, the drilling efficiency will decrease with flatter angles.

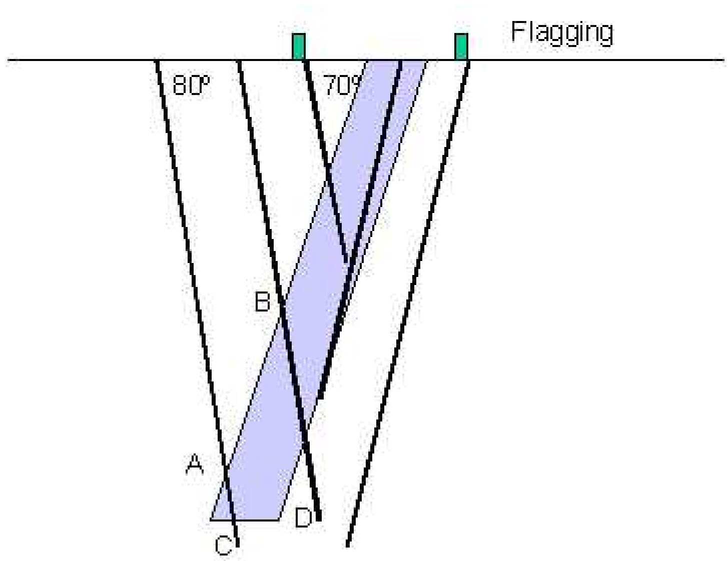

Figure 3. Section view of probe holes.

Another type of probe drilling is conducted by reverse circulation (RC) rigs. RC holes are drilled on an 8 m by 10 m pattern with a depth of 38 to 55 metres in mineralisation zones. Most of the holes are drilled from the hanging wall side of stopes and are inclined at 55 degrees towards the stopes. Grade control RC holes contribute significantly to both underground workings detection and delineation. It has been a great advantage to obtain ground condition information 2 to 4 benches in advance. In fact, RC drilling has detected a number of unmapped stopes. Another advantage of RC drilling is that RC holes can be used to deploy a laser survey system into a stope to map the cavity. This is discussed in the next section.

Cavity mapping using laser scanners

After a successful trial, KCGM purchased its first Cavity-Auto-Laser-System (CALS) for open stope (void) mapping. CALS is manufactured by the Measurement Devices Ltd in Scotland. CALS is designed to gather comprehensive three dimensional survey data from difficult, dangerous and inaccessible areas of a mine. The system gives the mine and geotechnical engineer the ability to quickly and safely survey abandoned mine workings.

The equipment consists of a pulsed laser range finder housed in a custom designed aluminum probe. Stepper motors drive the instruments 360 degrees in both the horizontal and vertical planes. Movement of the measuring head is controlled by a computer, which also stores the results of the survey.

The system is highly versatile and can be deployed in a number of ways including lightweight Boretrak rods that are deployed via a bore hole. The probe is controlled manually through the PC software or programmed to perform a number of user specified scans. Scans can be either by arc or chord distances and once the parameters are set there is no further need for operator intervention.

Data is displayed and logged in real-time and stored directly into a computer. The raw data can then be converted to a number of popular formats for direct import to mining software such as SURPAC, VULCAN or DATAMINE.

The CALS probe used at KCGM has a diameter of 100mm and is deployed into an open stope through a RC hole with a diameter of 165 mm. The RC holes are cased using PVC pipe. The CALS head is shown in Figure 4. Figure 5 shows the deploy system customized at KCGM.

Figure 4. The Cavity Auto-Laser Scanner (CALS).

Figure 5. The CALS deploy system using Boretrak rods.

The data strings from such surveys can be easily imported into Vulcan and then triangulated for 3D display. By knowing the coordinates, dip angle and orientation of the drill hole, CALS provides the spatial location and the shape of the cavity as demonstrated in Figure 6.

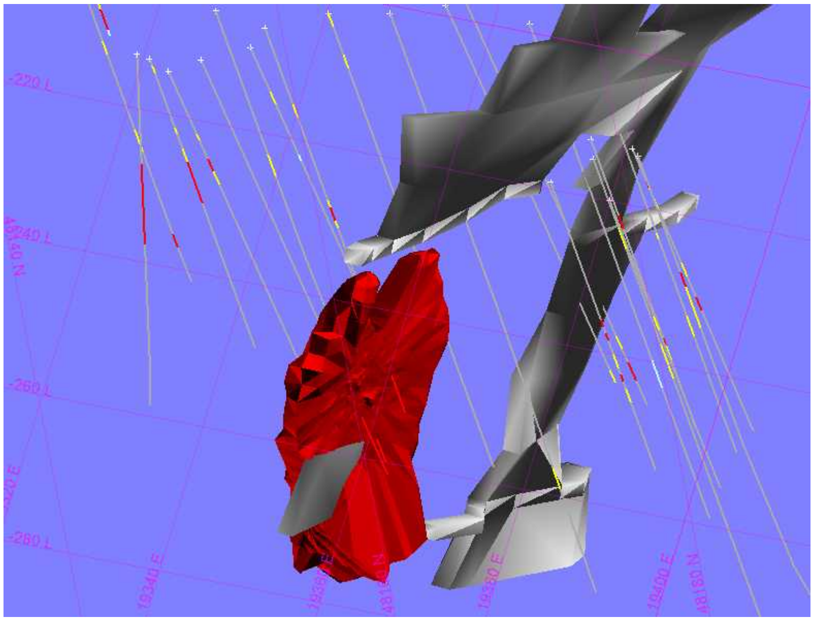

Figure 6. The Triangulation of CALS survey results. The triangulation in gray colour is the stope model from old records, the triangulation in red colour is the newly revealed void by CALS.

Geophysical methods

Various geophysical methods have been trialed on site for void detection. These methods include ground penetrating radar (GPR), micro-gravity, multi-electrode resistivity, micro-seismic tomography, transient electromagnetic method (TEM) and cross-hole radio wave tomography.

1. *Ground Probing Radar (GPR)*

Ground Probing Radar (GPR) has been investigated for void detection in the Fimiston Open Pit since 1990 by various researchers and organizations (Blair and Hunt, 1991; Siggins, Blair and Hunt, 1991; Turner, 1992; Bilki and Jiang, 1994; Morrongiello, 2003). Three types of GPR have been tested including PulseEkko (model IV and 100A) from Sensors and Software, SIR 10 from Geophysical Survey System and Ramac cu2 from MALA.

Three different frequencies were tested: 25, 50 and 100 MHz. The 50 MHz antennas performed well, achieving a maximum realistic penetration of about 15m in fresh rock. Compared to 50 MHz, the 25 MHz had a deeper penetration depth but much poorer resolution. The 100 MHz had a much better resolution compared to 50 MHz but much less penetration.

Open stopes are easier to detect than rock-filled stopes due to the similarity in electrical properties between the fill and the host rock. Clay and saline water have significantly adverse effects on GPR. Both are highly conductive and significantly attenuate radar energy. Hence, penetration depth is reduced. Broken ground due to sub-drill and blasts also attenuates radar energy and reduces penetration depth.

The condition of the pit floor significantly affects the reliability of the GPR data. The number of non-detection and false anomalies increase with degrading pit-floor conditions. In good floor conditions, ie. fresh rock without clay and saline water, a 100% detection ratio is achievable. False anomalies comprise an additional 30% of the total number of real targets. With poorer floor conditions, the detection ratio decreases to 50%, with false anomalies comprising an additional 60% to the total number of real targets.

2. *Micro-gravity*

Micro-gravity measures gravity change. For an open stope or a loose filled stope, low gravity is expected as the result of missing mass. A production trial was conducted for void detection in the Fimiston Open Pit in 1999 (Cowley, 1999).

A 5m x 5m pattern was used for data acquisition. Since the pit floor was relatively rough, it was quite difficult to level the gravity meter, taking about 6 to 8 minutes to level and acquire gravity data at each point.

After the data is acquired, terrain correction has to be applied by modeling. Once the correction is done properly, only those frequencies which are actually caused by the terrain (pit walls) will be removed. And the residual picture will show gravity contours with potential anomalies.

Figure 7 shows residual contours of gravity over a surveyed area. The colour changes from deep blue to deep red with gravity changing from low to high. Hence, the gravity contours show locations with potential underground workings. The deep blue colour at the upper left corner indicates “missing mass” and this was verified to be an open stope below the surface. Micro-gravity can scan 10 to 15 metres deep with reasonable resolution. The depth of workings can be estimated using the Euler method.

The major disadvantages of using micro-gravity are the slow data acquisition on site and the complication of data processing such as terrain correction. Earthquakes also have a very strong impact on data acquisition. A large magnitude earthquake can affect data acquisition for one to two days.

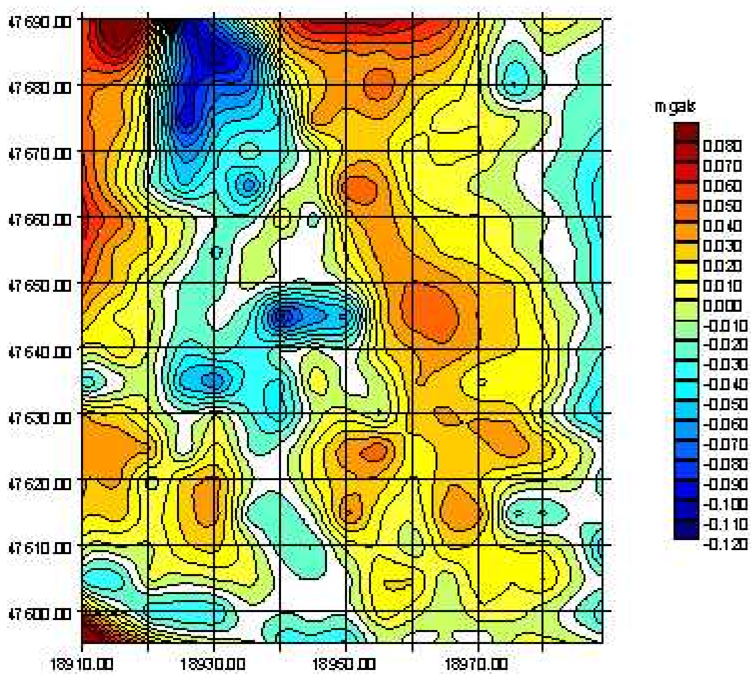

Figure 7. Residual contours of gravity over a surveyed area.

3.	*Multi-electrode Resistivity Method*

The Multi-electrode Resistivity Method measures the electrical conductivity of the medium under investigation. Material with different geo-electrical characteristics will have different electrical conductivity. It is assumed that open stopes, filled stopes and their host material should have different geo-electrical characteristics. By measuring and analyzing the distribution characteristics of different geo-electrical fields, underground workings should be able to be delineated from the host rock mass.

A trial was conducted in the Fimiston Open Pits in 2001 (Zhang *et al*, 2001). The site consists of a black and white flagging area with a known open stope about 7 metres below the surface as shown in Figure 8. Two surveying lines were defined oblique to the flagging tape. The Multi-electrode resistivity method was trailed along the line 1 and line 2.

In the experiment the electrodes were fixed to ground at 2 metre intervals. There were 64 electrodes used at one time. Three different data acquisition methods were used, the Wenner array, the Dipole-Dipole array and the Schiumberger array. The results obtained by different electrode array methods have shown that the Schiumberger array method gave the results closet to the real case. It also had the best transverse resolution and could approximately delineate the anomaly of underground workings.

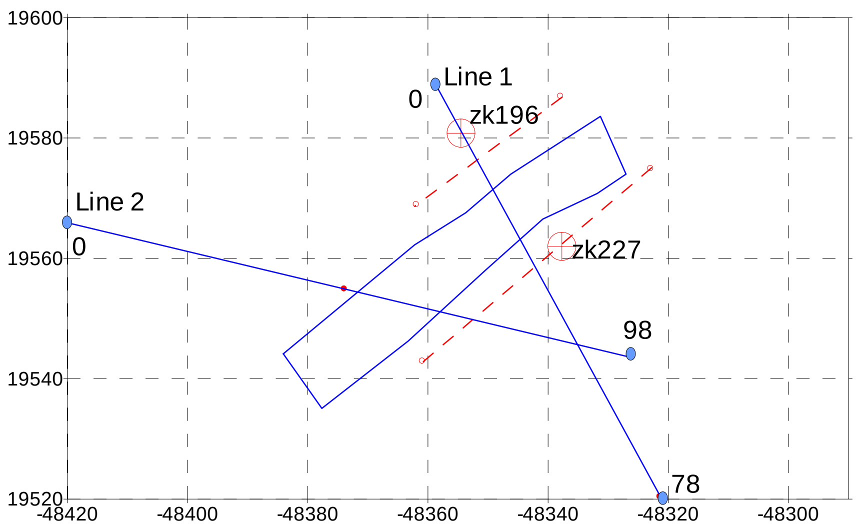

Figure 8. The layout of the trial site.

Figure 9 shows the resistivity profile along the survey line 2. The centre of the void is located at approximately 16m below the surface as shown in the figure with the roof and the floor of the void approximately at 8 m and 22 m below the surface respectively. The location of the void is 45 m from the survey origin along the line 2. The location of the void has been verified by probing drilling.

The high resistivity area at 21 m was another filled stope that was verified by drill cuttings from the production drilling. The high resistivity area at 69 m was due to the existing porphyry vein that was also verified by the drill cuttings from the production drilling. It is not clear at this stage why both the filled stope and porphyry had as high resistivity.

Theoretically, the resistivity method can scan quite deep. However, the effective horizontal detecting distance decreases with depth rapidly. It takes much longer time to scan a certain distance at large depth than it does at shallow depth. Furthermore, the resistivity method has very poor resolution as shown in the figure and it is quite difficult to outline the boundary of an anomaly.

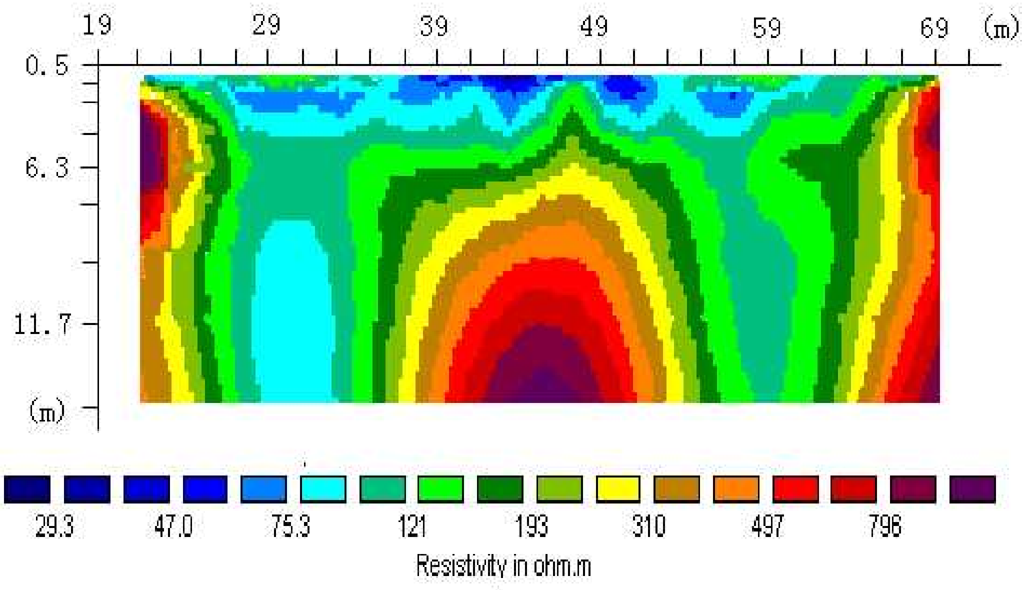

Figure 9. The resistivity profile over a 50m scanned distance.

We also conducted the measurement of Induced Polarisation (IP) along the line 1. It is very interesting to note that high IP zone exists around the underground workings as shown in Figure 10. It indicates that there are more metal minerals around the open void than the host material. In other words the measurement of IP can outline the mineral abundance zone. Hence, by measuring induced polarisation, we can also detect underground workings.

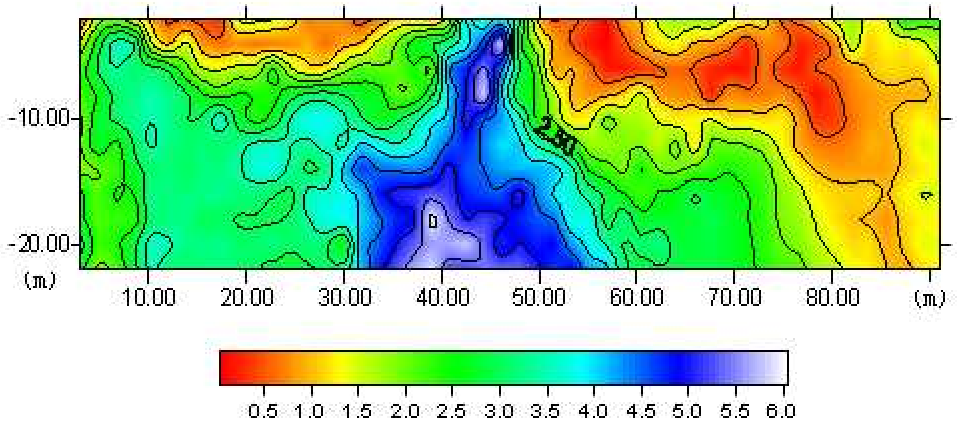

Figure 10. The IP contour plot along the line 2.

4. *The Cross-hole Radio Wave Tomography*

The Cross-hole Radio Wave Tomography utilises the absorption characteristics of electromagnetic waves when they travel in different mediums. The underground workings are assumed to have different conductivity when compared to the host rock and as such would cause the reflection and refraction of electromagnetic waves. By measuring the absorption difference of the electromagnetic waves travelling through the underground workings, the shape and location of any existing void could be defined.

The system consists of a single transmitter (source) and multi-receivers. Two boreholes are required, the source wave is induced at a given point in one of the boreholes and is received in the other hole at multiple consecutive points along the hole. Then the source point is moved to the next point along the hole and received in the same way in the other hole. By repeating the process, numerous compact rays are recorded and form the cross net in the investigation area. Tomography technique is used to model the cross net and outline the spatial location of any anomalies (Zhang, *et al*, 2001).

The trial was conducted along the survey line 1 as shown in Figure 8. Two 20 metre deep boreholes were drilled at each side of the flagging denoted as zk 196 and zk 227. Our preliminary test had shown that for working frequencies from 0.5MHz to 4.5MHz radio waves could propagate up to 50 m.

Figure 11 illustrates the moving pattern of the transmitter and the receiver in both boreholes. Figure 12 shows the image of the void obtained from the cross-borehole radio wave survey. According to the results from probe drilling, the cross-hole method outlined the back and floor of the void much more accurately than the sides. The width of the void obtained from the cross-hole method was much wider than the actual void width. This discrepancy was mainly due to the limitation of the borehole depth. Reasonable results can only be achieved if the borehole depth is much greater than the void height. The cross hole accuracy could also be improved by using multi-sections scanning if time allowed.

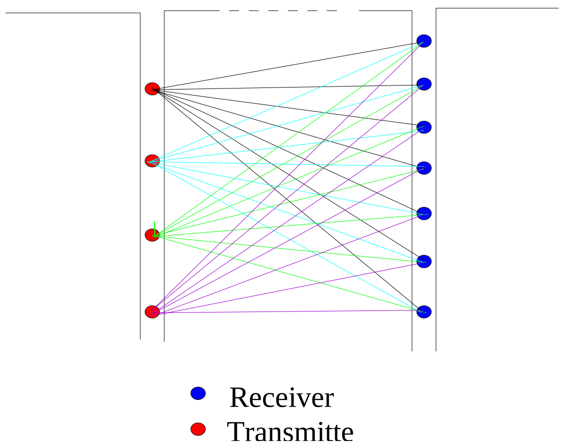

Figure 11. The scanning pattern of the cross-hole radio wave tomography.

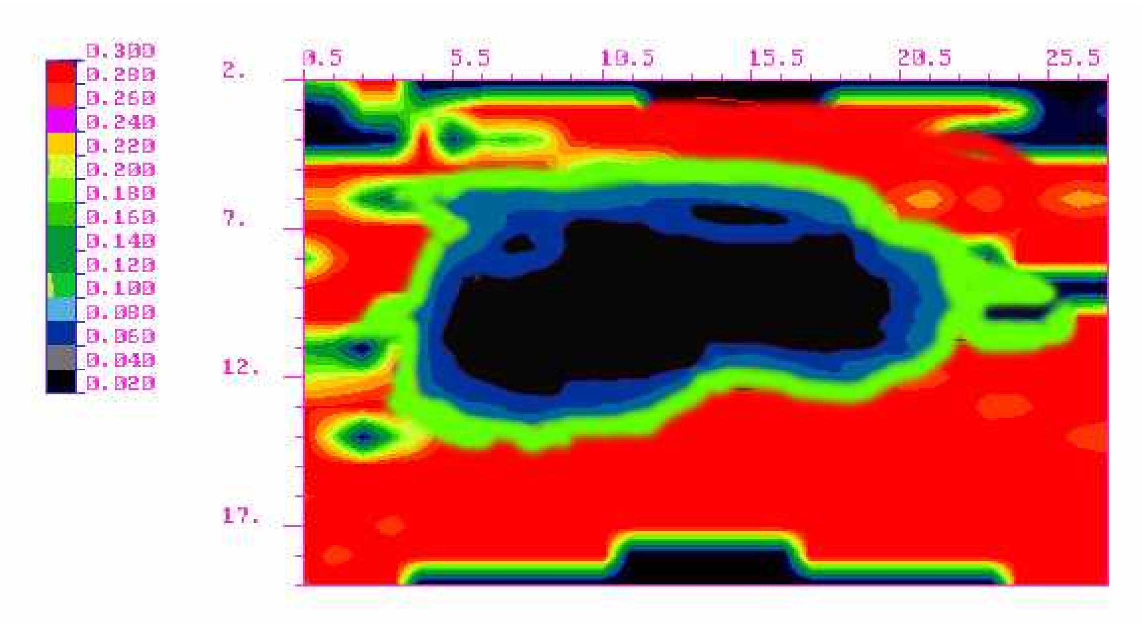

Figure 12. The image of the void obtained from the cross-hole radio wave tomography.

5. The Transient Electromagnetic Method (TEM) and Micro-Seismic Tomography

The Transient Electromagnetic Method (TEM) and Micro-Seismic Tomography have been tried with little success (Zhang, *et al*, 2001). The major obstacle for micro-seismic tomography was the broken layer on the pit floor. The broken material absorbs most of the seismic energy and prevents the seismic energy transmitting into ground. The major difficulty with the TEM seemed to be the penetration depth and resolution.

CONCLUSIONS

The management of the interaction between open pit operations and underground workings in KCGM's Fimiston Open Pit is a unique and exciting challenge. The open pit has progressed at a rapid rate which increases the challenges in working around underground openings. Operating procedures are continually modified and implemented to mine through a very complicated network of underground workings.

Probe drilling has been proven to be the most reliable method for underground workings detection and delineation. CALS, the laser scanner, is a very valuable tool for underground void mapping when a bore hole is the only available access.

Most of the geophysical methods were able to detect old working to certain degrees. GPR has achieved the best results among the methods. The detecting depth varied from several metres to about 20 metres. But the results were generally ambiguous and required post interpretation and verification.

The complex geological structures of the rock mass pose a major obstacle to the application of geophysical methods in the pit. The existence of geological structures, shear zones and faults often give false information and thus reduces reliability. Furthermore, broken material on the pit floor from sub-drill can reduce detecting depth by absorbing geophysical energy. Up to date, the application of geophysical tools has not proven to be a practical alternative that can be adapted to fit in with the production cycle. KCGM continues to have an open mind for the future in this regard, with ongoing evaluation of new alternatives as they are become available to the industry

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Zhang, S H, Zhang, Z L, Lu, S L and Wu, Y Q, 2001. Report on geophysical trials for underground workings detection at KCGM Fimiston Open Pits Operation. KCGM internal report. FIG 8 - View of sheet mesh fence installed under high wall.